

AD-A122 444

IMAGE SIZE RANGE AND TV CAMERA SEPARATION DISTANCES FOR 1/1

LARGE SECURE AREAS(U) AIR FORCE AEROSPACE MEDICAL
RESEARCH LAB WRIGHT-PATTERSON AFB OH W C SELF SEP 82

UNCLASSIFIED

AFAMRL-TR-81-94

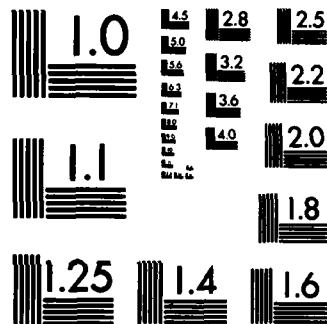
F/G 17/2

NL

END

FILED

DTG



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



IMAGE SIZE RANGE AND TV CAMERA SEPARATION DISTANCES FOR LARGE SECURE AREAS

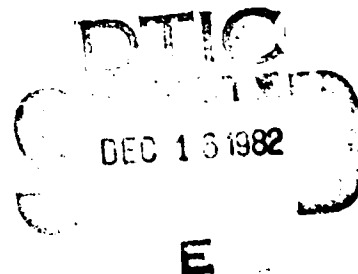
HERSCHEL C. SELF, Ph.D.

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY

SEPTEMBER 1982

Approved for public release; distribution unlimited.

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



AL A122444

WAC FILE COPY

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from Air Force Aerospace Medical Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
Cameron Station
Alexandria, Virginia 22314

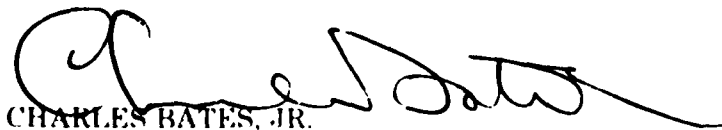
TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-81-94

This report has been reviewed by the Office of Public Affairs (PA) and the National Technical Information Service (NTIS). At NTIS, it will be available to the public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



CHARLES BATES, JR.

Chief

Human Engineering Division

Air Force Aerospace Medical Research Laboratory

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFAMRL-TR-81-94	2. GOVT ACCESSION NO. AD-A122444	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IMAGE SIZE RANGE AND TV CAMERA SEPARATION DISTANCES FOR LARGE SECURE AREAS		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Herschel C. Self, Ph.D.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Aerospace Medical Research Laboratory Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB OH 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62202F; 7184-12-06
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1982
		13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Cameras	Lenses	Surveillance
Detection	Targets	CCTV
Ergonomics	Recognition	Television Cameras
Images	Security	Human Factors
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>Closed circuit TV cameras frequently are outfitted with short focal length lenses to display terrain near the camera to a security guard. This method of employment causes three human factors problems: (1) usable range over which intruders are detectable and recognizable is quite short, (2) intruder images can vary greatly in size from the near to the far range, complicating intruder recognition, and (3) to cover long boundaries in large installations requires watching many TV display monitors. These problems can sometimes</p>		

BLOCK 20 CONTINUED:

be eliminated by moving the near range out to a few hundred feet, using longer focal length camera lenses, and having each camera look past the next one, covering its blind zone. On long straight fences the number of cameras and the amount of associated equipment can be drastically reduced. Initial and life cycle costs of large installations can be greatly reduced while easing the monitoring task. The general case is examined and the approach is applied to the Base and Installation Security System (BISS) when it is used to protect large installations.

PREFACE

This report was prepared in the Human Engineering Division of the Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed in support of the Base and Installation Security System (BISS) Special Project Office, Electronic Systems Division, Hanscom Air Force Base, MA. It was done under Project 7184, "Man-Machine Integration Technology," and Task 718412, "Human Engineering Application to Systems Design, Test and Evaluation."

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	



TABLE OF CONTENTS

	Page
INTRODUCTION	3
CURRENT SURVEILLANCE CAMERA USAGE.	4
AN ALTERNATIVE APPROACH FOR LONG STRAIGHT FENCES	6
NEAR AND FAR FIELD DISTANCES AND FENCE COVERAGE FOR BISS CAMERA INSTALLATIONS.	11
SUMMARY OF RESULTS	18

LIST OF ILLUSTRATIONS

Figure	Page
1 Useful TV Surveillance Range for Various Near Limits and Image Size Ratios	8
2 Far Field Distance Estimation From Camera Focal Length and the Effective Vertical Dimension of the Photocathode of the Closed- Circuit TV Camera	13
3 An Example of Camera Deployment with Cameras Having a 500mm Focal Length	15

LIST OF TABLES

Table	Page
1 Useful Ranges and Camera Separations for Various Image Size Ratios	7
2 Fence Coverage of BISS Camera Installations	12
3 Fence Coverage Equations for BISS Camera Installations.	13
4 Cost of Components for Covering 4,296 feet of Straight Level Fence with Cameras Having Different Focal Lengths	17

INTRODUCTION

Television cameras aimed at secure areas and enclosures are often used to supply images for the displays of closed circuit television monitors used by security personnel. Security guards are enabled, in effect, to be in many places at once while avoiding exposure to the elements, dangerous conditions, and immediate attack or evasion by terrorists, saboteurs, criminals, or enemy agents. Current doctrine and applications notions about covering the borders and fences of large secure areas have led to problems: (1) large numbers of TV cameras are required, (2) associated problems in monitoring many cameras, and (3) large variation in the size of intruder images on display, with the images of more distant intruders being quite small and containing few image details. All three of these problems are serious. Frequently not much can be done. However, when a secure or sensitive area is bordered by long straight stretches of fence, something can be done to reduce the magnitude of all three problems. This report looks at current practice and offers an alternative approach for areas having long straight fences.

CURRENT SURVEILLANCE CAMERA USAGE

High security areas are often enclosed by fences, frequently with barbed wire or barbed tape on top to make it more difficult for intruders to get over the fence. However, even the most effective security fences can delay a capable and determined intruder for only a very short time. A fence, by itself, offers little or no protection to an enclosed area so that it must be supplemented by other means, such as patrols, sensors connected to alarms, etc. To monitor a fence for intruders, there is, in some systems, a security monitor or guard located indoors who observes one or more CRT television displays. The pictures on display are supplied by closed-circuit television (CCTV) cameras aimed along the fence. The cameras are usually mounted on posts, often of a type that pivots to the ground for camera maintenance. Adequate fence security requires that every part of the fence be covered by at least one television camera. It is common practice to have two cameras for each expanse of fence, each "looking" toward the other. This arrangement permits the guard to observe a potential intruder through the CCTV camera that is closest to the intruder. Unless the intruder is exactly midway between the cameras, he can be observed through a camera that is less than half as far from him as the distance separating the cameras. If the intruder is too far from one camera, the guard simply looks through the other camera that also includes the intruder in its field of view.

TV cameras are usually installed so that their field of view includes fence that is not far from the camera. This nearest part of the fence is at a distance from the camera that may be called the near distance. This near part of the fence appears at the very bottom of the guard's TV display. Some current systems include fence that is about 30 feet away. To do this from a camera position higher than the fence, and still look down the fence for some distance, requires a TV camera lens that has a fairly short focal length. At the same time that near fence must be seen, adequate details of a man-sized intruder must be displayed on the guard's monitor for him to recognize an object as a human intruder. With a TV camera lens of short focal length, intruders cannot be recognized as people at long distances. This means that the separation between surveillance cameras cannot be large. Maximum camera separation would obtain when reliable intruder recognition is required for distances up to only slightly greater than halfway to the next camera. Here, one would depend upon the "look back" capability of dual coverage cameras. Minimum separation between cameras would obtain if reliable intruder recognition is required all of the way out to the next camera. This is sometimes required as a safety measure in case a camera becomes inoperative.

The permissible separation distance between TV cameras covering an expanse of fence depends upon the level of reliability that one desires in recognizing people as people from the displayed TV image. Reliability may be defined in terms of the probability of recognition. With current practice, this value is frequently set at .95. With the short focal length lenses discussed above, this yields a maximum range of about 350-400 feet. Beyond this range, detection and recognition probabilities are too low. When a very long expanse of fence has TV surveillance cameras about every 350 to 400 feet, dozens of cameras may be required for adequate security monitoring. The required number becomes even larger when the fence is not straight or when the terrain is not flat. Each camera has its own special expensive tilt-to-repair metal mounting post, buried coaxial cable and power supply lines going to the monitoring station. The many cameras, mounts and buried cables is costly. In addition, use of many cameras poses electronic and mechanical reliability problems and a requirement for having a large inventory of spare cameras and camera parts. Also, monitoring large numbers of cameras poses severe problems for surveillance operators. This monitoring problem is severe even when one looks only at fence areas where sensors located on or near the fence have sounded an alarm.

When an alarm is sounded and an intruder's presence is suspected, even the time taken to switch cameras for a closer look can be critical. A surveillance guard monitoring the CRT displays will frequently be taken unaware by an unexpected alarm, and lose a valuable couple of seconds or more. During this lost time, while he is "collecting his wits" and switching cameras on the displays, an agile fast-moving intruder may leave the scene, or find concealment, or even stop moving to make detection more difficult. He may even lie down for awhile in a small compact position to make detection difficult and unlikely. Clearly, having to switch cameras is undesirable. Even if the alarm system automatically switches the correct cameras onto the CRT monitors, the observer may lose valuable time by first looking at the picture from the most distant camera where the intruder's image is small and poorly resolved.

The size of an image on the TV monitor is inversely proportional to the distance from the TV camera of the object being viewed. A man twice as far from the camera has a display image that is only half as tall, etc. Thus, an additional penalty, and a severe one, incurred in some current practice (but not in the BISS system) with an attempt at a 30-400 foot fence coverage is that images at the limit of the camera range are quite small compared to images of intruders at the near range. It is apparent that the image size of a man 400 feet away is only $30/400$, or $1/13$ th as tall and $1/13$ th as wide as the image of a person at 30 feet. The image also contains only $1/13$ th as much image detail in each dimension. A variation of 13:1 from near to far is excessive. A large size range means that image size is neither a quick nor an accurate cue for the actual size of the imaged object. A large image size range should, if possible, be avoided.

AN ALTERNATIVE APPROACH FOR LONG STRAIGHT FENCES

When fences have only short straight runs, close camera spacing is unavoidable: many cameras must be used to obtain complete coverage of the fence. However, when enclosed areas contain very long straight expanses, something can be done to decrease the number of cameras required and to considerably reduce the size variation of the images of intruders with intruder distance from the camera. Suppose, for example, that a large image size range is cut down to 3:1 or to 2.5:1. Much can be gained by this. Fewer cameras mean less time lost in switching cameras or searching separate monitor screens. Also, the true size of objects imaged on the displays would be more apparent.

How the number of cameras can be reduced, while maintaining a satisfactory size ratio, is indicated by the data in table 1. The table lists the useful range, or feet of fence covered, of one TV camera for a variety of far and near viewing limits for image size ratios of 8:1, 6:1, 4:1, and 3:1. The reader may, if he so desires, readily calculate values for other size ratios. Select any particular near distance and multiply it by the size ratio to obtain the far distance or limit. Take the difference between far and near distances to obtain the useful range or range coverage. The focal length of the TV camera lens is then selected to obtain adequate image size and detail at the far range limit.

Table 1.

USEFUL RANGES AND CAMERA SEPARATIONS FOR VARIOUS IMAGE SIZE RATIOS

Size Ratio, $R = F/N$	Near Limit or Distance*, N	Far Limit or Distance $F = RN$	Useful Range or Range Coverage $S = F - N$	Camera Separation, Full Coverage, $C = F - 2N = S - N = N(R-1)$
8:1	700	5,600	4,900	4,200
	600	4,800	4,200	3,600
	500	4,000	3,500	3,000
	400	3,200	2,800	2,200
	300	2,400	2,100	1,800
	200	1,600	1,400	1,200
	100	800	700	600
	50	400	350	300
	25	200	175	150
6:1	700	4,200	3,500	2,800
	600	3,600	3,000	2,400
	500	3,000	2,500	2,000
	400	2,400	2,000	1,600
	300	1,800	1,500	1,200
	200	1,200	1,000	800
	100	600	500	400
	50	300	250	200
	25	150	125	100
4:1	700	2,800	2,100	1,400
	600	2,400	1,800	1,200
	500	2,000	1,500	1,000
	400	1,600	1,200	800
	300	1,200	900	600
	200	800	600	400
	100	400	300	200
	50	200	150	100
	25	100	75	50
3:1	700	2,100	1,400	700
	600	1,800	1,200	600
	500	1,500	1,000	500
	400	1,200	800	400
	300	900	600	300
	200	600	400	200
	100	300	200	100
	50	150	100	50
	25	75	50	25

Note: All table values are in feet. Values *not* adjusted for the height of the camera above the ground.

*Near limit is the closest part of the fence seen on the display. Objects at the near limit appear at the very bottom of the display. The far limit is not the distance to objects shown at the top edge of the display, but merely that distance out to which one wishes to look for intruders with the camera. Camera separations allow each camera to look past the next camera to cover that camera's blind spot caused by its near distance.

Examination of the data in the table, and shown in figure 1, reveals that if the near range scene, displayed at the very bottom of the table, is moved out to a few hundred feet the useful length of fence that can be adequately covered by one camera increases dramatically. In some current usage, with a 50-foot near range and an image size range of 4:1, total coverage of fence per camera is about 150 feet. As an example of what happens with increase in the near range, note the tabled data for a near range of 400 feet and an image size range for 4:1. The table shows that 1,200 feet of fence can be covered by one camera. Since $1,200/150$ is 8, this gives 8 times as much fence coverage per camera. Even if one has a requirement for the "look back" capability provided by dual camera coverage, the number of cameras is reduced by a factor of 8. If one does not use look back cameras, then each camera would have to clearly resolve human intruders about 400 feet (in the example) past the next camera to cover the blind area in front of the next camera. In this example there is an 8 times reduction in the number of TV cameras, camera mounting posts and power and signal cables. Looking in the last column of the table, note that in the example just discussed, camera separation is 800 feet and 100 feet, which yields the same ratio of 8:1 in number of cameras required.

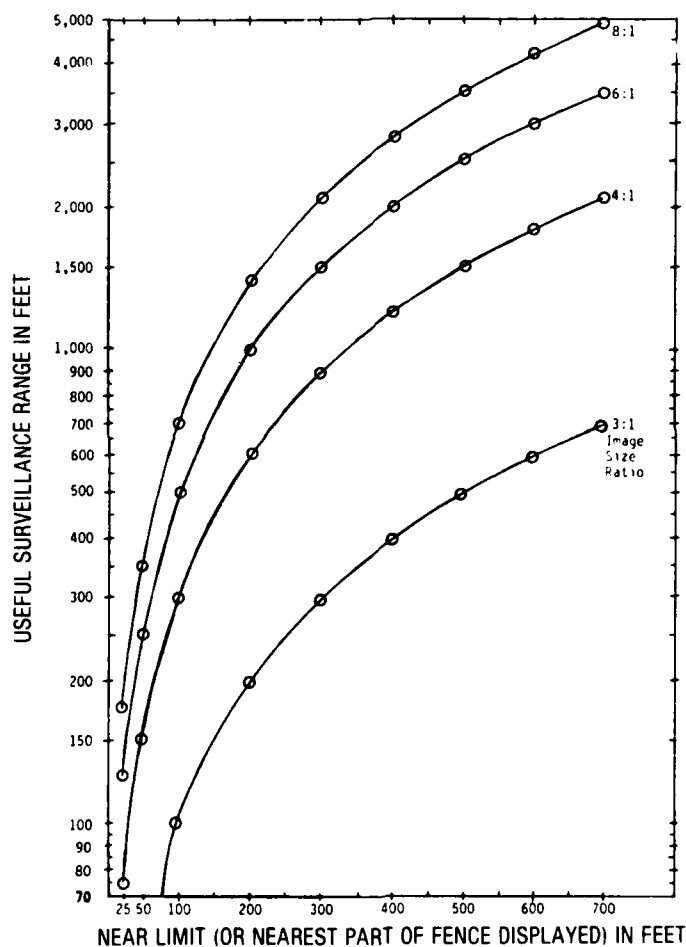


Figure 1. Useful TV Surveillance Range for Various Near Limits and Image Size Ratios

Note from the table that, with a 3:1 ratio, moving the bottom of the field (the near range) out to 400 feet gives a range coverage of 800 feet. If we subtract 400 feet to allow covering the blind spot in front of the next camera, 400 feet are left between cameras. For the 50 foot near limit, camera separation is only 50 feet, giving an 8:1 reduction in number of cameras, the same ratio as for a 4:1 image size ratio. As one more example, note that with a 200 foot near range and an image ratio of 6:1, a range of 1,000 feet is available. When one deducts 200 feet for the blind spot in front of the next camera, in the chain of cameras, a camera separation of 800 feet is obtained. The reduced fence coverage per camera with shorter near distances, as now usually used, has an advantage of requiring camera lenses of shorter focal length, which are less expensive; and fence surveillance capability is less influenced by haze, light fog or rain or snow. This is at the cost of more cameras, mounts and cabling. The data in table 1 are plotted in figure 1 where the rapid increase in amount of fence covered by one camera may be more apparent than it is in the table.

In the first example given in this report, with near distances of 50 and 400 feet compared with an image size range of 4:1 in both cases, far distances are in a ratio of 1,600/200, or 8:1. Thus, if a 1 inch lens is barely adequate to resolve intruders at 200 feet, an 8 inch focal length lens is required at 1,600 feet. Such a lens is quite large and expensive. Also, it probably is not commercially available with an automatic iris. Such a big lens would require a large housing to enclose it. Far ranges of over 1,500-2,000 feet may be inadvisable due to excessive loss of visibility at long ranges in light fog or light rain. The 1,200-foot range example is clearly an extreme case to emphasize a point.

Another point that should be mentioned is that the calculations in table 1 are not corrected for the height of the TV camera above the ground. Converting slant ranges to ranges along the ground to obtain the ground separation of successive cameras would change tabled values by only a negligible amount.

Before discussing the data in table 1, it is worthwhile to examine the terms "near limit" and "far limit". In the present report these concepts or terms were defined in a way that was conducive to quick simple computation of the useful range of coverage of a closed-circuit TV surveillance camera. The definitions used also made it simple to grasp the way in which useful coverage varied with the near limit and the size range. However, the terms do not have universal or standardized meanings. Many valid, but quite different, definitions are possible, depending upon the intent or goal of the user. Much confusion can result if this is not kept in mind.

As an example of a usage not at all like that in the present report, engineers at the Sandia Corporation working with the BISS (Base and Installation Security System) SPO (System Program Office) use a term that they call the "near field". This appears, superficially, to be similar to the term in the present report entitled "near limit". Actually, it is quite different. They define "near field" as that distance from the TV camera at which the horizontal view of the TV monitor includes the fence and 30 feet of the clear zone outside the fence. The distance to the terrain shown on the bottom of the display is not the "near field" for them. It is the "near limit" in the present paper. These engineers arbitrarily define "far field" as that distance from the TV camera at which eight TV scan lines are included in one vertical foot. These definitions are unique to BISS. The definitions of near and far limits which led to table 1 were, as noted, selected to allow the reader a quick grasp of the concepts and data computation. The main findings that follow from the table are widely applicable. A later section of this report looks at BISS camera installations and finds the same general results.

In one of the examples in this report, only one eighth as many TV surveillance cameras are required along a long straight fence on fairly level ground. In addition, only one eighth as many camera mounting posts and coaxial cables are needed. The cost of an installation is greatly reduced. The large reduction in equipment yields a large reduction in the frequency of malfunctions of equipment and in repair and routine maintenance work. Even the number of spare cameras that must be kept in stock may be reduced. Replacement of worn out equipment is reduced by a large factor. Much may be gained from a human factors standpoint, from the smaller number of different TV monitors that must be kept under watch by security guards. This can be critical in systems that do not have alarms automatically activated by sensors and which require constant watching.

The very great cost reductions that may be achieved by reducing the number of surveillance cameras required in an installation is not without some limitations and penalties. Larger near limits and far limits require the use of TV cameras with lenses that are much longer in focal length. Such lenses are physically larger, require larger and considerably sturdier mounts, and are much more expensive than short focal length lenses. The big lenses required may not be readily available on the commercial market, particularly with the automatic iris required in outdoor closed circuit TV cameras. Far limits or ranges of well over 1,000 feet required for large camera separations and a reduced number of cameras are inadvisable in some geographic locations due to excessive loss of visibility that occurs in even light fog, light rain, or light snowfall. For this reason, some surveillance camera locations may be better served by only small increases in near limit, with only a 2-3 times reduction in the number of cameras that are now using short focus lenses.

NEAR AND FAR FIELD DISTANCES AND FENCE COVERAGE FOR BISS CAMERA INSTALLATIONS

The Sandia Corporation is one of the BISS contractors. They have examined the coverage of BISS TV surveillance cameras for four short focal length camera lenses and have also examined the image supplied by one of somewhat longer focal length. Upon request, they supplied the near field distance and the far field distance for the four lenses. Their focal lengths are 12.5, 25, 50, and 75 millimeters. Remember, from earlier discussion, that in BISS applications the near field distance is defined as that distance from the TV camera where the camera displays on the TV monitor the fence and the area outside of the fence up to a distance of 30 feet measured perpendicular to the fence. The far field distance is that distance in which one vertical foot is covered by eight TV scan lines. Since BISS TV surveillance cameras have 480 scan lines, this 8 lines/foot yields $480/8 = 60$ feet. Thus, the far field is at that distance at which the field of view is 60 feet in vertical extent. This requirement for the far field originated in the need of the human observer to have about eight TV horizontal scan lines on an adult human intruder lying on the ground while crawling or when attempting to be inconspicuous.

To enable calculation of near and far field distances, N and D , respectively, and their difference, R , or fence coverage, N , D , and R were each plotted against the camera lens focal length, F , using the N and D values supplied for the four lenses mentioned above and shown in table 2. As expected, all three quantities (N , D , R) were linear functions of lens focal length. The 12.5 mm lens, with its short near field, departed slightly from the straight lines provided by the other lenses. In other words, near field distance, N , far field distance, D , and camera fence coverage, R , all increase with lens focal length in accordance with the equation $Q = aF + b$, where Q is the quantity of interest, F is camera lens focal length, and a and b are numerical constants whose value depends upon whether Q is N , D , or R .

Figure 2 shows that the far field distance of a TV surveillance camera set up to meet BISS requirements is linear with TV camera lens focal length, and is given by the formula $D = AF$ where A is a constant. For BISS this constant is 60 divided by the effective vertical dimension of the photocathode of the TV camera. Using the far field distance of 471 feet supplied for the 75 mm lens, the computation shown in figure 2 yields the equation for far field distance in feet as $D = 6.28 F$, where F is in millimeters.

The BISS cameras are set up above the fence and just outside of it, i.e., are offset so as to clearly see the fences outside and the ground area near it. For lens focal lengths of 25 mm and greater, the near distance, N , and the fence coverage or range, R , are so large relative to the offset of the camera that N , D , and R are essentially linear with lens focal length, F .

The linear equation for fence coverage or range may be written as $R = aF + b$. For the 75 mm and 25 mm lenses the Sandia Corp values of D and N yield $R_{75} = D - F = 471 - 187 = 284$, and $R_{25} = 158 - 63 = 95$, respectively. Plugging these values of R into the equation $R = aF + b$ yield two equations: $284 = 75a + b$ and $95 = 25a + b$. Solving for a and b yields the equation for R , which is $R = 3.78 F + 0.50$.

TABLE 2
FENCE COVERAGE OF BISS CAMERAS

Data Source	Lens Focal Length	Near Field Distance	Far Field Distance	Fence Covered = Range
	F	N	D	R = D-N
Sandia Corp.	12.5 mm	35	83	48
	25	63	158	95
	50	126	315	189
	75	187	471	284
Computation by Formula	100	248	628	380
	150	374	942	568
	200	496	1,256	760
	250	620	1,570	950
	300	744	1,880	1,810
	350	868	2,200	1,330
	400	992	2,510	1,520
	500	1,240	3,140	1,900
	550	1,360	3,450	2,090

Focal Length in mm. Other values are in feet. Computed values are based on $N = 2.48F$, $D = 6.28F$ and $R = D - N = 3.80F$.

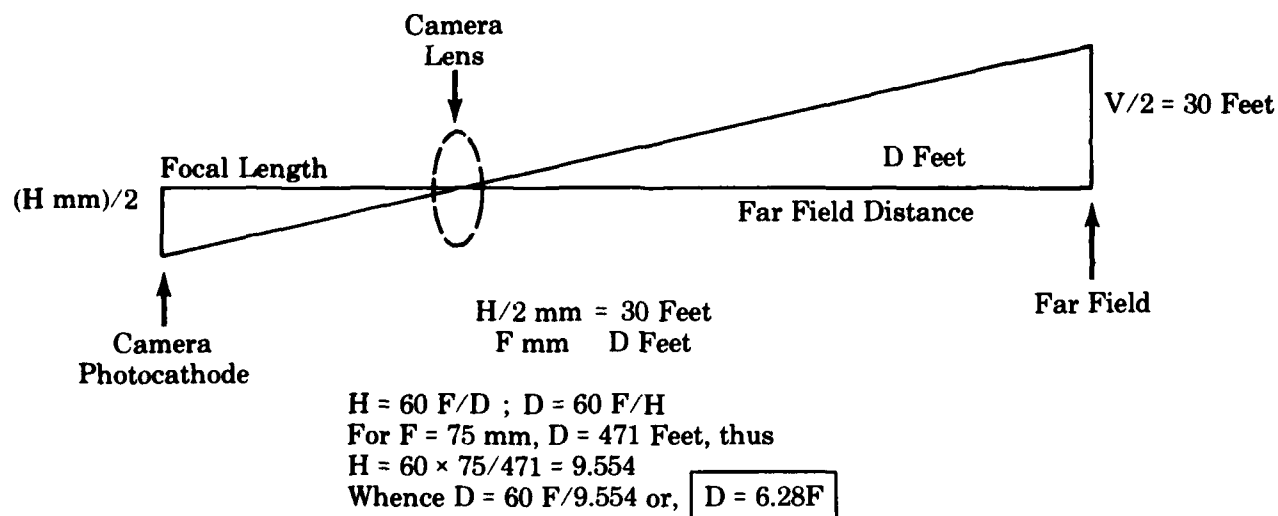


Figure 2

Far Field Distance Estimation From Camera Focal Length and the Effective Vertical Dimension of the Photocathode of the Closed-Circuit TV Camera

TABLE 3
FENCE COVERAGE EQUATIONS FOR BISS CAMERA INSTALLATIONS*

Quantity	Definition of Symbol	Equation	Source
N	Near Field Distance	$N = 2.48F$	Focal Length
D	Far Field Distance	$D = 6.28F$	Focal Length
R	Range or Fence Coverage	$R = 3.80F$	Focal Length
R	Range or Fence Coverage	$R = D \cdot N$	D, N
R	Range or Fence Coverage	$R = .605D$	D
R	Range or Fence Coverage	$R = 1.53N$	N
F	Camera Lens Focal Length	$F = 2.89R$	R
F	Camera Lens Focal Length	$F = .605D$	D
F	Camera Lens Focal Length	$F = 1.53N$	N

*For TV camera lens focal lengths of 50 mm or more.

In a similar fashion, the near distance is $N = aF + b$, with the N values for the 75 and 25 mm lenses yielding $187 = 75a + b$ and $63 = 25a + b$. Solving for a and b yield the equation $N = 2.48F + 1$. The same approach for the far field distance yields the equations $471 = 75a + b$ and $158 = 25a + b$ and the solution of the equations yields $D = 6.06F + 1.5$. This may be contrasted with the value of $D = 6.28F$ derived in figure 2 using only the 75 mm camera lens. Actually, the two equations differ in the value of D for a 75 mm lens by only 3.18% and for a 600 mm focal length lens by only 3.46%, both values being less than the normal manufacturing tolerance of $\pm 5\%$ in lens focal length.

The definition of R is that it is the difference between the far field distance and the near field distance, $R = D - N$. This yields $R = 6.28F - (2.48 + 1) = 3.80F - 1$, very close to the $R = 3.78 + .5$ derived earlier from simultaneous equations. In fact, for a 75 mm lens the R values differ by .13%, while for a 600 mm lens they differ by .46%, each only a small fraction of lens focal length manufacturing tolerances. For all practical purposes, $R = 3.80F$.

The equation for N of $N = 2.48F + 1$ can be shortened to $N = 2.48F$ for focal lengths of 50 mm or more with negligible effects on the value of N . With this proviso, the basic equations for the BISS installations become: $R = 3.80F$ (or $R = D - N$), $N = 2.48F$ and $D = 6.28F$. These equations, and others derived from them, are listed in table 3. The equations enable values of R , N , and D to be calculated for focal lengths of over 75 mm. This is done in table 2 which gives camera coverage for lenses up to 550 mm in focal length.

Examination of table 2 reveals that a 25 mm focal length camera lens covers only 95 feet, a quite short length of fence. Even the 75 mm lens covers only 284 feet of fence. This is much better, but still requires many cameras to cover a few thousand feet of straight fence. Going to quite long focal lengths is a different story. Note from table 2 that the coverage of a 500 mm lens is 1,900 feet. Even with this much coverage, the image of an intruder at the far field distance, 3,450 feet, is only $1/(3,450/1,360) = 1/2.5$ that of an intruder at 1,360 feet, the near field distance. Thus the image size range is not excessive. As a matter of interest, for BISS camera installations the image size ratio, which is numerically the same as the ratio of far field distance to near field distance, is $6.28F/2.48F = 2.5$ for all lens focal lengths.

As the far field moves out or away from the camera, the near field also moves out, leaving a longer "blind" zone in front of the camera. For example, while the far field with a 500 mm lens is, from the table, 3,140 feet from the camera, the near field is 1,240 feet. This blind zone of 1,240 feet has to be covered by another camera. This coverage could be accomplished in any one of several ways. Figure 3 shows one way that might be used. It is only a suggestion. The blind zone immediately in front of the first camera could be covered by a "look back" camera which also looked back past the first camera. For example, the look back camera might be located to look past C1 by 40 feet. This means that the second camera, C2, with a 500 mm lens, would be located $D - 40 = 3,140 - 40 = 3,100$ feet in front of C1. Then C1 would cover the blind zone of C2 and also the blind zone of the second forward-looking camera, C3. Thus, C3 would be located at $D - N = 3,140 - 1,240 = 1,900$ feet in front of C1. The fourth camera, also forward-looking, would be $1,900 \times 2 = 3,800$ feet from C1, the fifth at $1,900 \times 3 = 5,700$ feet from C1, etc. The first five cameras, including the "look back" one covering the first camera and its blind zone would cover 8,800 feet of fence, with every camera and its blind zone covered by another camera. Note that only C2 would look back, all succeeding cameras in a long chain would look forward, the blind zone in front of each camera being covered by the previous one. As this example shows, using a long focal length lens, camera separations of 1,900 feet could cover a very long straight fence with only a few cameras. Similar calculations show that with a 50 mm lens, successive cameras would be separated by $D - N = 315 - 126 = 189$ feet, a clearly inadequate spacing when large perimeters must be kept under TV camera surveillance.

- Notes: (1) Vertical dimensions are not to scale.
 (2) The lines from the cameras to the ground are lines going to far field and near field distances. Cameras look past the far field.

Distance From First Camera

Camera	X
1	0
2	R-1,900
3	D-40=3,140-40=3,100
4	2R=2x1,900=3,800
5	3R=3x1,900=5,700
* look back camera	

NUMBER OF CAMERAS REQUIRED:

D = Total length of fence covered by cameras.
 N = Number of forward-looking cameras.
 $N_1 = N+1$ (To include 1 back-looking camera) = total number of cameras.
 $D = (\text{Near range}) + NR = 2.48F + 3.80FN$, so that $N = (D - 2.48F) / 3.80F$ and
 $N_1 = N+1 = N_1 = (D + 1.32F) / 3.80F$

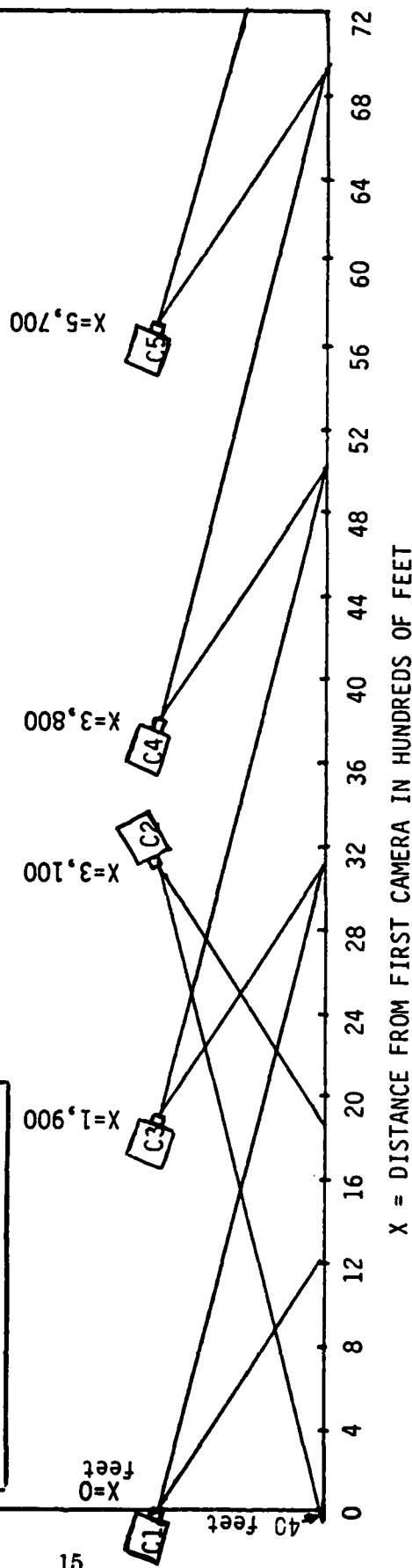


Figure 3. An Example of Camera Deployment with Cameras Having a 500 mm Focal Length

The cost savings realizable by using TV cameras with long focal length lenses can be quite large. The estimated cost for equipment in an example will vary with the assumptions one makes about cable arrangements, cost of nonstandard components, etc. As a practical realistic example, suppose that TV surveillance cameras must be installed to cover 4,296 feet of straight and fairly level fence. This is just over 0.8 of a mile. Let the cameras be deployed in the type of arrangements shown in figure 3. However, instead of the extreme focal length of 500 mm used in the figure, long lenses of 200 mm and 135 mm and a short lens of 50 mm will be used. The formula given in figure 3 for the number of cameras required when deployed as in the figure is $N_1 = (4,296 + 1.32 \times 200) / (3.80 \times 200) = \text{six TV cameras}$, five of them looking forward the one looking back, when 200 mm lenses are used. The same coverage for 135 mm lenses requires 9 cameras. For the 50 mm lens, the number required is $N_1 = (4,296 + 1.23 \times 50) / (3.80 \times 50) = 22.96 = 23 \text{ TV cameras}$. This is a large number of cameras to cover only 0.81 miles of fence.

Using the July 1981 costs, the basic TV camera without a lens cost the BISS SPO \$650. The mounting posts, which have a swing down capability for maintenance, cost \$2,500 each. The armored coaxial cable for the cameras is \$.45 per foot. The 50 mm lenses are \$190 each and the 135 mm lenses, the longest off-the-shelf lens with automatic diaphragm, costs about \$1,000 each. The cost of the 200 mm lenses are estimated as about \$1,500 each. The environmental housing, which contains the camera and its lens, costs \$531 each. Housings for the larger lens cameras would cost more. The costs for these are estimates. It is possible that the 200 mm lens camera would require a sturdier post than the standard one to be more resistant to wind induced vibration. If so, each one might cost as much as 500-\$1,000 more than the standard post.

Keeping in mind that component costs in an estimate will vary with one's assumptions, table 4 permits cost comparisons for 200 mm, 135 mm and 50 mm TV systems. For the approximately 0.8 mile example in the table, the initial or component cost, not including labor costs, for the 50 mm system is \$76,461 higher than that of the 200 mm system. If sturdier mounts are required in the latter at an additional cost of, possibly, \$1,000 each, the saving is still about \$70,000. For the 135 mm system, component cost is only about as much as for the 50 mm system, with a savings of \$61,976. Clearly, as this example shows, initial cost savings for components with longer systems is very large. Cost of ownership over the life of a system must also be taken into account. Installation, calibration, maintenance, replacements, and spares are all expensive. The longer lens systems in the example, with their far fewer cameras, cables, mounts, connectors, etc. not only have a lower acquisition cost, cost of ownership is also far lower.

TABLE 4
COST* OF COMPONENTS FOR COVERING 4,296 FEET OF STRAIGHT LEVEL FENCE
WITH CAMERAS HAVING DIFFERENT FOCAL LENGTHS

ITEM	FOCAL LENGTH OF TV CAMERA LENS			
	200 mm	135 mm	50 mm	
TV Camera without Lens Cost	6 6 x \$650 = \$ 3,900	9 9 x \$650 = \$ 5,850	23 23 x \$650 = \$ 14,950	
Camera Lenses with Automatic Irises Cost (Estimated for 200 mm Lenses)	6 6 x \$1,500 = \$ 9,000	9 9 x \$1,000 = \$ 9,000	23 x \$190 = \$ 4,370	
Camera Environmental Housing Cost (Estimated for 200 & 135 mm Lenses)	6 6 x \$700 = \$ 4,200	9 9 x \$600 = \$ 5,400	23 23 x \$531 = \$ 12,213	
Camera Mounting Post, Swing Down Cost	6 6 x \$2,500 = \$15,000	9 9 x \$2,500 = \$22,500	23 23 x \$2,500 = \$ 57,500	
Armored TV Cable ++ Cost (@ \$.45/Foot)	11,816 feet 11,816 x \$.45 = \$ 5,317	19,672 feet 19,672 x \$.45 = \$ 8,852	51,433 feet 51,433 x \$.45 = \$ 23,145	
Cable Fittings at Camera Cost (Not including other end Fittings)	6 6 x \$100 = \$ 600	9 9 x \$100 = \$ 900	23 23 x 100 = \$ 2,300	
TOTALS	\$38,017	\$52,502	\$114,478	
Savings over 50 mm Lens	\$76,461	\$61,976		

* Costs are as of July 1981 and do not include digging cable trenches, installing and burying cables, calibration and maintenance, spares, monitoring equipment, etc.

* Costs of these items are only estimates.

++ Footage based on cable going to a monitoring station 500 feet from the first camera and on a perpendicular to the line of cameras at the first camera. All lines in one ditch.

SUMMARY OF RESULTS

Examination of the general case for increasing the terrain coverage of TV surveillance cameras and a theoretical examination of potential BISS installations with fewer and more widely spaced TV cameras both lead to the same set of conclusions. The more important findings are as follows:

1. The number of closed circuit TV surveillance cameras required to protect a fence or other boundary can sometimes be greatly reduced. This is possible when (a) the boundary is long and straight over fairly level ground, (b) the system is now using short focal length lenses, and (c) the geographic area is arid or desert-like, with little or no poor visibility due to atmospheric conditions.
2. This reduction in number of TV cameras required can be accomplished without increasing the size range of the images on the monitor of intruders over the length of boundary covered by any one camera. In some systems now using short near field distances, this image size range may even be reduced while also reducing the number of TV cameras required.
3. The number of cameras required can be reduced by employing longer focal length camera lenses. This increases the separation between cameras. While both near field distance and far field distance increase, the difference between them also increases.
4. Far field distance, D , near field distance, N , and their difference, R , which is the camera coverage of the boundary or fence, are all linear functions of camera lens focal length. For the particular system examined in the present report, the BISS system, these quantities were, respectively, $D = 6.28F$, $N = 2.48F$, and $R = 3.80F$. Clearly as focal length increases, far field distance increases over twice as fast as near field distance, thus accounting for the improvement in R with increases in F and N .
5. Cameras with longer focal length have greater image magnification, making them, in proportion to their focal length, more sensitive to wind induced vibration, buffeting, and swaying. They thus require sturdier camera mounts than cameras of shorter focal length.
6. Although fewer lenses and cameras are needed, big lenses cost much more per lens and may not be readily available with automatic irises, which are required for outdoor installation.
7. An example was discussed, admittedly somewhat extreme, where the number of cameras required was reduced by a factor of 7. Even with much more modest reductions, there can be a huge reduction in the initial cost of an installation and in the required maintenance. Reliability of equipment is enhanced.
8. Security guards have to monitor the TV displays whose images are supplied by the TV surveillance cameras. With a smaller number of cameras, their task can be considerably simplified and possibly be made more reliable. This result would be particularly true for those surveillance systems whose lack of intruder detectors and automatic alarms activated by the detectors requires observers to be constantly vigilant and constantly scanning displays on TV monitors.
9. Larger separation between cameras is not always desirable due to greater loss in image quality on the TV monitors when the weather is inclement. Fewer cameras more widely spaced is an option that is feasible only in geographic locations that have generally clear atmosphere, little haze and only infrequent or light rain or snow. Usually this is true of arid or desert areas.